Technology Readiness Assessments for IT and IT-Enabled Systems

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To ensure that the Department of Defense (DoD) is approving Milestone B decisions for programs that are technologically mature, the director of Defense Research and Engineering (DDR&E) implemented Technology Readiness Assessments[1] (TRA) as a DoD 5000 requirement. With the continued and growing dependence of major DoD systems on information technologies, the TRA Deskbook [1] is being updated to address the unique aspects of computer systems, hardware, and software technologies for embedded systems, business management information systems, net-reliant systems (e.g., command and control), and infrastructure systems (e.g., net-centric enterprise services). The DDR&E tasked the Institute for Defense Analysis, assisted by representatives from DoD services and agencies to develop the revised guidelines. This article summarizes the revised guidelines, including the new Software Technology Readiness levels, and provides examples in applying the updated guidelines to major defense acquisitions.

Technology Readiness Assessments[1] (TRAs) are conducted on major defense acquisitions, which often consist of complicated machinery and hardware systems that depend on advances in state-of-the-practice technologies. The intent of a TRA is to document that, prior to system design and development, there is a reasonable expectation that the acquisition is technically feasible. In other words, the effort being undertaken is likely to be realized with currently available technologies. The TRA's focus is technologies – it is not intended to address the capabilities of the acquiring or developing organizations, nor does it attempt to assess processes being applied during development.

The TRA is mandated by Department of Defense (DoD) Directive 5000.1 and DoD Instruction 5000.2. The TRA Deskbook [1], approved by the deputy undersecretary of defense for Science and Technology (DUSD[S&T]), describes the TRA requirements and process in detail. It has recently been revised to address some of the unique needs of information technology (IT)-based systems. Completion of the TRA allows early identification of technology issues so they can be addressed as an integral part of the development process. Potentially costly changes in the later stages of system development, where even small modifications can be costly and time consuming, can be mitigated or avoided.

The current TRA process follows three basic steps: identification of critical technology elements (CTEs), evaluation of CTE maturity using technology readiness levels (TRLs), and maturation planning. The program manager and the Component Science and Technology executive are jointly responsible for determining the final list of CTEs, assessing its maturity, and finalizing any necessary maturation plans. The DUSD(S&T) is responsible for oversight of the TRA process and providing a yearly summary report to Congress.

Motivation for the Revised TRA Deskbook

The current TRA/TRL model works well for traditional hardware-oriented systems being managed to a set of capabilities and requirements documents with few interdependencies with other systems. However, an increasing number of defense acquisitions are either information systems or traditional systems with increasing dependencies on computer technologies. Those that are not classified in the acquisition system as information systems directly may have a large IT component or a large dependency upon success of the IT component. To address this fundamental change in the types of acquisitions, a corresponding change in the approach to TRAs was needed. This keeps TRAs relevant to DoD's changing acquisition needs while providing the same level of technology analysis and management associated with traditional hardware systems.

The problem faced with information systems is that very few hardware and software elements can be singled out as CTEs. As a result, the TRA skips over many important issues that lie outside of hardware and software. These can collectively be termed IT issues and include interfaces, throughput, scalability, external dependencies, and information assurance. These are integral to how the system is designed. The use of these technologies is critically dependent upon a system architecture that drives system interdependencies and complexities. The system architecture defines which of these issues are important to consider and which may have associated CTEs beyond those directly related to system functionality.

The Nature of IT Systems

IT systems fall into four basic types that the DoD procures. While many intermediates, flavors, and special cases exist, characterizing DoD acquisition into these four types allows us to more readily ensure that our revised approach to TRA is effective and provides useful advice on conducting the TRA. Following are the four IT system types:

- Business systems.
- Net-reliant (battle management) systems.
- Network infrastructure (or services provider).
- Embedded systems.

While each of these systems has many points of overlap, they also have unique requirements; we will briefly discuss each one. Some acquisitions may include a combination of the above, so the TRA may include characteristics of several of these types.

Business Systems

Business systems acquisitions typically consist of a small set of large commercial off-the-shelf (COTS) products to which the organization will adapt. The business system may be characterized by using off-the-shelf information system components and COTS software together in a new environment to support the business and management functions of an organization.

Typical business systems include finan-

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cial management, personnel management, and enterprise resource planning. The ITs are the primary CTEs with their configuration driving additional CTE designation. Typically, the CTEs will align with the COTS products selected. Additional CTEs may come in the form of case legacy conversion tools, and environments may be critical to keep backward compatibility and seamless data access.

Net-Reliant Systems

Net-reliant systems provide military (warfighting) functions that rely on data exchanges with physically disparate elements. These systems involve large amounts of data push (control) or data pull (awareness) function and are typically command and control; battle management systems; or intelligence, surveillance, and reconnaissance systems. The net-reliant system is characterized by an intense *real-time* requirement, a heavy reliance on exchanges with external information sources or consumers, and may be pushing the state-of-the-art in data fusion and blackboard collaboration.

The emphasis in these systems is having computers assist humans in awareness and decision-making processes across physically separate warfighting and sensing elements. The software run-time environment for real-time applications may be critical here as the functionality may be safety- or security-related.

The ability to keep communication lines open is likely to lead to a number of unique CTEs by itself. The architecture will include strong information assurance requirements. Reach-back support and voyeur channels will most likely identify critical elements from the information assurance perspective. CTEs may also enable efforts to manage data, translate data, and establish composability (how systems bind to one another). The IT that realizes the system and the elements cited above should be considered for CTEs.

Network Infrastructure

Network infrastructure system acquisitions provide the equipment and capabilities necessary for the successful operation of net-reliant systems. Backbone and Services systems acquisition technology issues often manifest themselves as the maturity of standards (often, but not always commercial) and standardization that transcends individual COTS or government off-the-shelf (GOTS) products. Timeliness and robustness of services are major technology considerations that should be included when assessing maturity. The network infrastructure is characterized by large database management and *glue logic* to execute and retrieve services across a Wide Area Network of varying security. This environment is critical and unique and the IT elements are most certainly a CTE. Since COTS has not operated in this environment before, anything of a critical nature must be demonstrated, and the separation of security streams must be considered as a CTE.

Embedded Systems

Embedded warfighting systems such as a tank, ship, or aircraft are systems whose functions are focused on warfighting platforms, and whose functionality is enabled by IT but not driven by IT itself. Embedded systems emphasize using computer hardware and software to automate internal functions of a weapon system such as platform control and status, sensor signal and data processing, and weapons tasking. The embedded systems range from simple to complex and emphasize autonomous functionality in timeframes meaningful to a computer.

Embedded system acquisitions may include full development (where the information technology is a primary issue) to modification of existing systems (information architecture is firm, and demonstrated in an operational environment) where information technology is not an issue. The environments that convert software to firmware may be CTEs. *Real* time is often critical – making the timing associated with any calculation routine a part of the CTE determination consideration. Few opportunities exist to use COTS or GOTS beyond microprocessors and operating systems because these systems are largely unprecedented.

Summary of Changes to the TRA Deskbook

To address the unique aspects of IT and IT-based systems, the DUSD(S&T) has developed a set of software TRLs (see Table 1) and has provided additional guidance and examples on how environmental issues unique to IT systems should be addressed in IT system TRAs.

CTE Determination

CTE determination for IT and IT-based system TRAs must begin with the basic expectations (requirements, capabilities, functions) for the acquisition. The TRA includes a mapping of CTEs to those expectations. For IT and IT-based systems particularly, expectations may not be driven from a top-down set of anticipated functionality.

Some IT system acquisitions include technology modernization issues driven by supportability and compatibility that could provide a source of nontraditional CTEs such as online software configuration management and update technologies. Other IT systems acquisitions include modernization as a way to realize transformational concepts. Integration and roll-out efforts may also be technology-enabled with new or novel technologies enabling those parts of the acquisition as well.

The new suite of IT-unique CTEs requires a different line of thinking when marketplace considerations, technology trends, and the short shelf life of IT technologies are viewed in the context of long-lived DoD acquisition programs. CTE considerations in these situations might transcend an individual product, but may consider the capabilities provided by a stable set of suppliers and customers as a whole. For example, middleware products supported by consortium-facilitated standards might provide the necessary technology stability while the actual suite of available products may change from year to year. Careful consideration is needed when selecting a particular technology that is vendor-specific and not widely embraced across both the vendor base and industry- and government-standard bodies.

Environments and Information Architecture

The above considerations imply that, at Milestone (MS) B of the DoD 5000 series, there is some form of notional architecture for the system acquisition. Whether it is a high-level diagram of interrelationships between COTS products or a set of data flow diagrams for developed software elements, the existence of system architecture must be available. Architectural considerations are present in the consideration of environments in the analysis of CTE maturity. A COTS CTE may be mature in that it has been used by several large organizations outside the DoD for similar purposes, but the DoD's unique architecture renders much of that maturity uncertain because of differences in information assurance, data management, etc. To reach the upper levels of maturity (TRLs 6 and higher), a successful operation in a similar or identical environment to that anticipated for the acquisition is necessary. The maturity of the definition of the system architecture itself and how CTEs are integrated and demonstrated as a result of this will impact the maturity assessment of a particular CTE.

IT systems have the additional complexity that architectures and architectural

TRL	Definition	Description	Supporting Information
1	Basic principles observed and reported.	Lowest level of software technology readiness; a new software domain is being investigated by the basic research community. This level extends to the development of basic use, basic properties of software architecture, mathematical formulations, and general algorithms.	Basic research activities, research articles, peer-reviewed white papers, point papers, and early lab model of basic concept may be useful for substantiating the TRL level.
2	Technology concept and/or application formulated.	Once basic principles are observed, practical applications can be invented. Applications speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies using synthetic data.	Applied research activities analytic studies, small code units, and papers comparing competing technologies.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Active research and development is initiated. The level at which scientific feasibility is demonstrated through analytical and laboratory studies. This level extends to the development of limited functionality environments to validate critical properties and analytical predictions using non-integrated software components and partially representative data.	Algorithms run on a surrogate processor in a laboratory environment, instrumented components operating in laboratory environment, and laboratory results showing validation of critical properties.
4	Module and/or subsystem validation in a laboratory environment, i.e., software prototype development environment.	Basic software components are integrated to establish that they will work together. They are relatively primitive with regard to efficiency and robustness compared with the eventual system. Architecture development initiated to include interoperability, reliability, maintainability, extensibility, scalability, and security issues. Emulation with current/ legacy elements as appropriate. Prototypes developed to demonstrate different aspects of eventual system.	Advanced technology development, standalone prototype solving a synthetic full-scale problem, or standalone prototype processing fully representative data sets.
5	Module and/or subsystem validation in a relevant environment.	Level at which software technology is ready to start integration with existing systems. The prototype implementations conform to target environment/interfaces. Experiments with realistic problems. Simulated interfaces to existing systems. System software architecture established. Algorithms run on a processor(s) with characteristics expected in the operational environment.	System architecture diagram around technology element with critical performance requirements defined, processor selection analysis, and Sim/Stim laboratory buildup plan. Software placed under configuration management. COTS/GOTS in the system software architecture are identified.
6	Module and/or subsystem validation in a relevant end-to-end environment.	Level at which the engineering feasibility of a software technology is demonstrated. This level extends to laboratory prototype implementations on full-scale realistic problems in which the software technology is partially integrated with existing hardware/software systems.	Results from laboratory testing of a prototype package that is near the desired configuration in terms of performance, including physical, logical, and data and security interfaces. Comparisons to tested environment to operational environment analytically understood. Analysis and test measurements quantifying contribution to system-wide requirements such as throughput, scalability, and reliability. Analysis of human-computer (user environment) begun.
7	System prototype demonstration in an operational high fidelity environment.	Level at which the program feasibility of a software technology is demonstrated. This level extends to operational environment prototype implementations where critical technical risk functionality is available for demonstration and test in which the software technology is well integrated with operational hardware/software systems.	Critical technological properties are measured against requirements in a simulated operational environment.
8	Actual system completed and mission qualified through test and demonstration in an operational environment.	Level at which a software technology is fully integrated with operational hardware and software systems. Software development documentation is complete. All functionality tested in simulated and operational scenarios.	Published documentation, product technology refresh build schedule, and software resource reserve measured and tracked.
9	Actual system proven through successful mission-proven operational capabilities.	Level at which a software technology is readily repeatable and reusable. The software based on the technology is fully integrated with operational hardware/software systems. All software documentation verified. Successful operational experience. Sustaining software engineering support in place. Actual system.	Production configuration management reports, technology integrated into a reuse *wizard*, and out-year funding established for support activity.

Table 1: *Revised Software TRLs*

issues transcend any single CTE. In these cases, additional mitigation plans may be warranted when technology issues are revealed as a result of environmental considerations, or the architectures are defined after MS B as a part of the development effort.

Technology Maturity and Demonstrations

The current requirement for major defense acquisition programs at MS B is that all CTEs be maturity level TRL 6 or higher, or have a maturation plan to achieve TRL 6 or higher when needed. Achieving TRL levels of 6 or higher depends upon CTEs successfully running in a relevant or operational environment.

Prior to MS B, activities such as concept development and experimentation should include a significant amount of prototyping or pilot demonstrations. It is important that these demonstration efforts collect the necessary information to inform future acquisitions regarding the successes and weaknesses of a vendor product or a particular implementation so that the program development and supported capability expectations are known. In some cases, a concept demonstration may use a development environment that will require upgrading for production.

Laboratory and pilot demonstrations are likely to examine the interconnections, database manipulations, and preliminary data on throughput, execution, and resource utilization. External dependencies for specific technologies and technology insight should be identified in detailed Technology Transition Agreements (TTAs) between the supplying organization and the receiving acquisition program office (more information on TTAs can be found in the TRA Deskbook). Protocols needed to resolve the external dependencies are worked out. If external dependencies involve another program office's development, then schedules are synchronized, and risk abatement activities are undertaken that may include alternative elements and key action dates (for executing alternate plans) tied to the external program's ability to demonstrate its technology readiness.

It is during these early prototype and demonstration activities that tradeoffs are often made as to what elements of software reside in each part of the architecture, distributed versus centralized data and control, information assurance aspects, and preliminary data on throughput and network requirements. It is here that most of the hardware and software elements are identified. At its conclusion, we have a detailed architecture and a definition of the totality of the relevant environment. This, in turn, allows for system/subsystem model or prototype demonstration in a relevant environment that is needed for TRL 6 and higher. This detailed architecture is the work breakdown structure for critical technology assessment. In many instances the actual elements may be off-the-shelf and not a technology issue, but their integration and the architecture are technology issues. Often, the *glue logic* that allows the various elements of the system to work together will be a critical technology.

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Advice for TRAs on the Various Types of IT Systems

Business Systems

Because business management systems will largely consist of COTS products, the TRA should begin with an analysis of the maturity of the chosen products. Critical COTS products will be those that provide mission-essential functionality but are either new or novel by organizational experience, or because of the environment in which they will be running have elements on which the COTS products have not been used.

Typically, these products have been used in non-DoD organizations of commensurate size so a high degree of maturity is expected. However, the DoD's execution environment has a number of unique aspects that prevent us from assuming that success outside the DoD will automatically imply success for us, including information assurance, technologies for handling classified data, unique legacy applications, net-centricity, data management mechanisms, number of users, etc.

The TRA should include not only the CTE maturity but also a detailed analysis of environmental issues that could impact the ability of the COTS products to successfully execute. Finally, the environmental assessment should also include the ability of the collection of products to successfully run together.

As an example, a systems center wants to change its financial management and accounting system to a suite of commercial products used by many major corporations. The center did a series of pilots with the anticipated COTS applications on their existing hardware and operating environment to understand both the impacts to the users as well as the viability of the applications in the unclassified and classified systems on which financial and accounting data is stored and managed. Upon reasonably successful conclusion of the pilot programs, the systems center decides to proceed with the conversion with some minor modifications of the chosen suite of applications.

For the TRA, consideration of the CTEs begins with a listing of the COTS products being used in the project along with any external technologies such as the existing desktops and servers on which these applications will run, upon which success of the effort depends. Several of the *minor* applications might fall off the list because these programs are not critical to successful functioning of the system or because there are many other applications that could reasonably take their place. The existing suite of desktop computers, networks, and servers would not make the list of CTEs either because that IT has been successfully operating. The proposed list of CTEs consists of the small list of applications that are both critical to success and are new or novel in the sense that they have not run with DoD information assurance technologies, DoD legacy applications, and in the DoD's data environment.

The proposed list of CTEs is reviewed and the final list is analyzed to determine TRL ratings based upon industry experience and pilot results. Where a CTE was not piloted and has not been previously used by the DoD in a similar environment, it can achieve a rating of no higher than TRL 5. A piloted CTE can typically achieve a rating of TRL 6 or 7, assuming no major problem was encountered during the pilot effort. The TRA should also include a careful analysis of the environment and multi-application issues that might not have been considered when viewing the applications by themselves.

Issues such as timeliness of system-wide transactions, impact of information assurance policies, and the presence of multiple sources of data on the system should be considered along with the need for these applications to peacefully coexist on the computing system as part of the environmental analysis. Where a CTE is

less than TRL 6, or an environmental issue raises significant concerns, a maturation plan should be developed and any corresponding risk item entered into the program manager's risk management system.

Net-Reliant Systems

For net-reliant systems, the TRA process should start with the set of proposed capabilities and examine the criticality of the technologies' associated capabilities. Because the solution is likely to consist of a mix of COTS, GOTS, and developed software, the TRA will likely encompass all elements of an IT system. These technologies should be viewed in the context of their ability to move and manage data with external systems so the environmental considerations may have unique technology aspects by themselves. Some of the ability to move data will depend upon capabilities provided by the Net Infrastructure systems. As a minimum, these dependencies should be identified and briefly analyzed. Where the infrastructure piece is immature, or presents a new environment for COTS/GOTS, the analysis for the specific COTS/GOTS will need to be considered.

An acquisition, in this case, might be a command/control or sensor net that manages and assimilates data from a variety of physically separated and disparate platforms. This type of system might include an improved version of several GOTS products enabled by a small suite of COTS technologies combined with upgrades to existing data communications networks to achieve an end-to-end capability across existing warfighting platforms.

The CTE list will focus on the COTS and GOTS products that are new or novel as supported by previous experience and demonstrations. The CTE list will also include any cross dependencies with other acquisition efforts such as upgrades to the communications equipment to support the net-reliant system. Where such a dependency exists between military programs, the TTA plays a critical role to detail the interdependencies between the acquisition, resource sponsor, science and technology activity, and other project managers to develop, deliver, and integrate a technology or product into the acquisition.

Much like other systems, higher levels of maturity are achieved by pilot or operational experience in an environment that closely resembles the one anticipated for final operation. The central processing and display suite may or may not be a CTE depending upon the amount of operational experience with the anticipated set of technologies. Where a CTE is determined to be a maturity less than TRA 6, the appropriate maturation plan and risk items should be established and noted in the TRA.

Network Infrastructure

Network infrastructure TRAs need to consider the maturity of both the technology standards under which the netted-elements will be interoperable as well as the maturity of technologies associated with uniquely acquired elements of the infrastructure acquisition (data services, networking, etc.). CTEs should be drawn from both sources and consider the interaction and compatibility of both sets of technologies. Because these acquisitions will become an integral part of the run-time environment for other systems, there could be additional technology considerations for the ability to roll these technologies out to the other three types of IT systems. TRA should not stray into analysis of the roll-out process unless that process is enabled by a specific technology such as automated, net-enabled configuration management tools.

An example in this area might be a new network combining land lines, radio frequency links, and a suite of servers for data and application hosting to support a combination of business and warfighting systems. Here the CTE analysis will start with a set of technologies taken from the anticipated system architecture and consider any new or novel aspects to the applications such as data rates, operational hardening (harsh environments, jam resistance, DoD-unique encryption), and authentication or collaboration services that will impact the ability of the proposed suite of technologies to provide the required capabilities.

As with net-reliant systems, there will likely be a combination of COTS and GOTS products combined with some operational experience of a smaller scale. In this situation, the acquisition may not depend upon other acquisitions to fulfill its requirements but may be the dependency for several other acquisitions. The net-infrastructure acquisition may be signatory on multiple TTAs as a supplier of a critical technology for other systems. Where such TTAs exist, they should, as a minimum, be noted in the TRA. As before, achieving ratings of TRL 6 or higher depends upon pilot or operational experience.

Embedded Systems

Embedded systems are largely DoD-unique warfighting capabilities that are enabled by IT systems rather than driven by IT systems. While improvements in IT capabilities (memory density, power consumption, processing speed) are critical to warfighting systems, most of the functionality is not commercially available, resulting in large amounts of developed software or software reused from previous embedded systems acquisitions. IT technologies are not generally CTEs in and of themselves except where the unique requirements of the embedded system (such as radiation hardening) result in the development or use of military-unique technologies. With our growing dependence on software, the sheer scale of software development or integration may be considered a CTE where enabled by a particular set of technologies that are new or novel.

For example, assume the acquisition is a complex warfighting platform such as an aircraft, ground vehicle, or ship. In these types of acquisitions, the capabilities of the platform are enabled by computers, but the computers themselves are not new or novel. Here, the CTE analysis begins with an architecture of the major warfighting functions (rather than specific hardware or software elements), or subsystems where domain maturity exists. The analysis in this case might show that neither the functions nor the realization of those functions in hardware and software is new or novel. However, the anticipated design of the platform includes consolidation of all the major computer-based functions on a reconfigurable suite of computing resources (processors, memory, and display stations) networked across the platform.

Here, the TRA for the IT elements of the platform will focus on the ability of available technology to support this reconfigurable suite of computing resources and run all the anticipated applications in a safe, reliable, timely manner as documented in the design scenarios. This situation will likely result in a single, complex TRA for the computing suite that should be supported by significant piloting and prototyping prior to MS B to achieve ratings greater than TRL 5.

Note that with the complexities of today's acquisitions, a system may contain elements of two or more of the system types noted in the preceding sections. In these cases, as well as any of those falling into a single bin, the need for experienced, professional judgment is critical. A TRA is not a substitute for a project manager and acquisition center staff who are technically qualified and actively involved in an acquisition. The TRA provides a focal point and emphasis on technology issues such as major milestone reviews, and is a voice for the efforts of the technical staff and their contributions. One common theme that occurs in all these types of

acquisitions is the need for prototyping and demonstrations to provide a sound basis from which to proceed.

Summary

In an effort to assure that major acquisition programs adequately address technology issues, the DoD requires a TRA. The TRA should assist program offices in the evaluation and maturation of technology issues present in DoD acquisitions as well as provide the approving acquisition official assurance that the program under review has a sound technology foundation. In today's information systems, the TRA includes both the hardware and software of the system as they fit within the architecture used to integrate these elements and the intended environment in which they will run. IT is becoming a critical factor in the success of modern DoD information systems. The TRA provides a chance to analyze a program and assess the technological maturity of its hardware, software, and IT. For technologies of insufficient maturity, a program of demonstrations and prototypes should be established to provide a mature set of ITs that are ready to support system development when needed.◆

Reference

1. Deputy Under Secretary of Defense for Science and Technology. "TRA Deskbook." Washington: DoD, Sept. 2003 <www.defenselink.mil/ddre/doc/tra_deskbook.pdf>.

Note

1. None of the text in this article is official policy or guidance on TRAs. Readers should refer to the DoD 5000 series, the Acquisition Guidebook, and the TRA Deskbook for the latest approved policy and guidance.

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